Modeling the groundwater potential of Nadvirna district using analytical hierarchy and GIS methods

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**SUMMARY**

Groundwater is a crucial water source for many regions, including Nadvirna district in Ukraine's Ivano-Frankivsk region. With rising tourist activity and potential surface water pollution, assessing sustainable groundwater availability is critical amid global climate change.

This study employs the Groundwater Potential Index (GWPI) method, integrating Analytic Hierarchy Process (AHP) to enhance precision by considering various factors. Hydrological maps, encompassing drainage density, rainfall, land use, slope, soil type, geology, and linear relief density, are generated.

Results classify Nadvirna district into four zones: insufficient potential (0.166 sq. km), medium (71,915 sq. km), high (140,629 sq. km), and very high potential (0.554 sq. km). These findings signify generally favorable hydrogeological conditions and significant groundwater resources, with areas holding promise for groundwater.
Introduction. Groundwater is one of the most important sources of water supply for different regions of our planet and Ukraine. They play a key role in providing drinking water to the population and maintaining ecosystem functions. The study of their spatial and temporal features in each particular region, the likelihood of pollution and forecast prospects in connection with global climate change is an urgent scientific problem.

Nadvirna district, located in the Ivano-Frankivsk region of Ukraine (Figure 1), is no exception in this regard. Ensuring sustainable and reliable groundwater availability in this region, given its significant tourist use and the vulnerability of surface water (the main source of water supply today) to pollution, is an important task in the face of rising global temperatures and likely decreased precipitation (Arkhypova et al., 2022).

![Figure 1](image-url)

**Figure 1** Nadvirna district, Ivano-Frankivsk region, Ukraine. Study area for determining the groundwater potential zones

The study used the method of the Groundwater Potential Index (GWPI), which is a tool designed to quantify the hydrological condition of groundwater resources in a particular region. This index takes into account various factors such as groundwater depth, water supply, water quality, hydraulic properties of groundwater layers and many others. The GWPI assessment helps to understand how groundwater can meet the needs of the population and the economy, as well as to identify the dynamics of hydrological factors in a changing environment (Klymchuk et al., 2022).

The purpose of the study is to assess the groundwater potential of Nadvirna district, Ivano-Frankivsk region.

Method and Theory. The Analytic Hierarchy Process (AHP) method was used in the context of developing the Groundwater Potential Index (GPWI) (Arulbalaji et al., 2019). It is believed that AHP helps to structure and take into account the various factors that affect the groundwater potential in the study area.

The AHP method determines the significance of various factors affecting the groundwater potential in the study area, such as groundwater depth, water quality, hydraulic properties, geological structure, etc (Avdullahi & Hajra 2023). The application of the AHP method to the development of the GPWI makes the assessment process more objective and scientifically sound, which in turn helped us to make informed decisions on groundwater management. The more theoretical approach of AHP allows us to improve the accuracy and reliability of the GPWI index, ensuring greater efficiency in the development and management of water resources in the study region (Figure 2).

The GPWI formula was used to determine the zones:

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GWPI = \sum_{w=1}^{m} \sum_{j=1}^{n} (W_j \times X_i),
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where GWPI is the groundwater potential index; $W_j$ - weighting factor for factor $j$; $X_i$ - the value of factor $i$; $n$ - number of factors; $m$ - number of assessment options for factors.

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**Figure 2 Flow chart of the methodology used for Groundwater Potential Zones Mapping**

**Results.** The evolution and flow of groundwater is mainly controlled by the material features of the lithology, surface and subsurface soil features, drainage structure and patterns, while groundwater recharge is influenced by precipitation, land use and infiltration rates (Baeza & Corominas, 2001). By creating a hydrological map of drainage density, we get information about the distribution of water and its movement in the area where it accumulates and how quickly it infiltrates into the soil, which is important for controlling the distribution of runoff and regulating the infiltration rate in the hydrological system (Kravchynskyi et al., 2021).

The second type of map - rainfall - identifies the locations and times of intense precipitation that affect water enrichment and allow for the prediction of water flows and the development of water management strategies (Kravchynskyi et al., 2021).

Land use and land cover (LULC) map shows the distribution of different soil types and land use, which affects infiltration processes and water availability. The slope map allows you to determine the energy of the water flow by identifying areas with large slopes.

The soil map indicates differences in water infiltration into the soil, which affects groundwater storage and availability. The geologic map shows the distribution of geologic formations, controlling water infiltration, movement, and storage. The linear relief density map shows areas with increased hydraulic conductivity, increasing the ability of water to penetrate the soil and distribute over the surface (Chowdhury et al., 2010) (Figure 3).

As a result, we obtained the following indicators. In the Nadvirna district, the first zone, which has insufficient potential, covers a small area of approximately 0.166 square kilometers. The second zone of medium potential covers a much larger area, about 71,915 square kilometers. The third zone of high potential covers the largest area, about 140,629 square kilometers. This indicates generally quite favorable hydrogeological conditions of the study area and the presence of significant groundwater resources. The fourth zone of very high potential is located in Nadvirna district, although its area is very small - only 0.554 square kilometers. This is a zone of potential sources of high quality groundwater (Figure 4).

These data provide important information on the different levels of hydrogeological potential of different zones in the study area. This analysis can be useful in developing strategies for water management and nature conservation in the region, as well as strategic planning for the development of the tourism industry and resorts in Nadvirna district of Ivano-Frankivsk region.
Figure 3 Information maps that contain information about a particular parameter and that reflect various hydrogeological aspects of the study area: "Drainage density", "Rainfall", "Land use and land cover (LULC)", "Slope", "Soil", "Geology" and "Linear relief density".

Figure 4 A map of the distribution of regions by different groundwater potential based on the analysis of all created maps with an analytical hierarchy.

Conclusions. This study was the first to use the Analytical Hierarchy Process (AHP) and GWPI methods to analyze hydrogeological conditions and determine groundwater potential in the Nadvirna district of Ivano-Frankivsk region, which is the most touristically used in the Carpathian region of Ukraine. This methodology allowed us to obtain a comprehensive map of the distribution of areas with different groundwater potential based on the analysis and analytical hierarchy of seven previously developed maps of factors influencing quantitative groundwater indicators. Using the AHP and GWPI method, it was possible to assess and classify the hydrological potential of the Nadvirna region in detail for the first time, which will allow for scientifically based measures to be taken to conserve and rationally use groundwater resources in the developing tourist region.

References